ELECTRON BEAM DEPICTING METHOD, MOTHER DIE

MANUFACTURING METHOD, MOTHER DIE, METALLIC MOLD

MANUFACTURING METHOD, METALLIC MOLD AND OPTICAL ELEMENT

BACKGROUND OF THE INVENTION

The present invention relates to an electron beam depicting technique and, particular to a technique for applying electron beams to form a predetermined pattern, for example, a diffraction pattern corresponding to an optical element, on a substrate as an exposure target.

In recent years, a CD and DVD, for example, are widely used as an information-recording medium, and many optical elements are used in the precision apparatus such as reading apparatus for reading such a recording medium. To ensure reduced costs and compact configuration, a plastic optical lens, rather than a glass-made lens, is more often used as

the optical element such as an optical lens employed in this apparatus.

The aforementioned plastic optical lens is manufactured by general injection molding, and the metallic molds used for injection molding operation are formed by general cutting operations.

In recent years, the required level of specifications and performances of the optical element has been raised. For example, when manufacturing the optical element having a diffraction structure on the optically functioning surface, the metallic mold must be provided with a surface for forming a diffraction structure in order to carry out injection molding of the optical element.

However, if an attempt is made to form a fine configuration such as a diffraction structure on a metallic mold by a cutting tool employed in the molding technique or working technique currently employed, working accuracy is deteriorated and the strength and service life of the cutting tool are reduced. Thus, precision working on the order of submicrons or even less has been difficult so far.

Especially in the pickup lens used in the medium such as a DVD, as compared with the CD-ROM pickup lens, diffraction structure of higher precision is required to cope

with an increase in the recording density. The required

working accuracy is on the level smaller than the light

wavelength, for example, on the order of nm. The prior art

working method, however, has failed to meet such high-

precision working requirements.

In the meantime, to form a predetermined pattern on the

surface of a substrate including an optical element, an

optical aligning method, for example, a method using an

aligner based on mask exposure technique has been employed.

By way of an example, an aligner for patterning a

predetermined shape on the surface of a substrate such as the

wafer substrate (photo mask) of a semiconductor may be used

for patterning on the surface of the aforementioned optical

element or for machining of a metallic mold. However, the

apparatus for wafer substrate has a problem in that only a

flat material can processed. Further, in the apparatus for

wafer substrate, the working depth of the substrate is

controlled in terms of exposure energy. However, in the case

of precision working of a diffraction grating for optical

elements and others or creation of a photonic crystal, the

structure shorter than the wavelength of the applied light

must be accurately formed on a non-planar surface such as a

lens. Thus, an aligner according to the aforementioned

control method is not suitable for fine patterning of the required level.

A laser beam method is another candidate for consideration. Laser beam is sometimes used for working on the order of microns, but the beam diameter is optically controlled, and beam convergence is limited. In this sense, this method is not suited for working on the order of submicrons, especially on the level close to the wavelength of light. Further, since a sufficient depth of focus cannot be obtained, it is necessary to utilize such a mechanical means as auto focusing at all times. This is one of the causes for discouraging high-precision working. Especially when high precision is required in the patterning of an optical element having a curved surface (including a 3D configuration having a surface changing on a macroscopic scale), this problem becomes serious.

Thus, this art can be employed in the patterning of a substrate having a planar form, but is not suited for forming a fine pattern on the substrate having a dynamic 3D configuration such as a curve. This has created a problem in this art.

To manufacture a metallic mold for such an optical lens, an attempt has been made to use an electron beam

depicting apparatus to form a diffraction structure on the
optical function surface of the optical element serving as
the mother die. (See the Patent Document 1, for example).

In the aforementioned electron beam depicting
apparatus, electron beam is applied to the surface of a
substrate as a model of the optical lens. A predetermined
dose of beam is used to perform scanning operation within a
predetermined, whereby binary or blaze-shaped diffraction
structure is formed.

[Patent Document 1]

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Incidentally, the minimum resolution of dose
(hereinafter referred to as "minimum dose resolution") is
determined by the minimum time resolution of the analog-to-
digital converter of the electron beam depicting apparatus.
Therefore, dose adjustment is made in a conspicuously
stepwise manner, especially when patterning is to be
performed at a high current value within a limited time.
Thus, even if efforts are made to form a smooth sloped blaze
surface in the formation of a blaze-shaped diffraction
structure, the sloped surface of the blaze obtained after
development of the substrate becomes stepwise in shape, due

to the magnitude of the aforementioned minimum dose resolution. This has created a problem in this art.

If the sloped surface of the blaze becomes stepwise in shape as described above, the optical characteristics of the optical lens are deteriorated; with the result that diffraction efficiency is reduced in particular. Further, when the consideration is given to the product quality, the aforementioned disadvantage will cause product value to be reduced. To improve the diffraction efficiency of the optical lens and to enhance product value, the sloped surface of the blaze must be made as smooth as possible in shape.

To solve such problems, it would be possible to perform patterning using a large beam diameter (at the defocusing position of electron beam, for example), thereby getting a smooth shape of the sloped surface of the blaze obtained after development of the substrate. In this case, however, a problem arises in that the rising shape becomes less sharp in the edge portion of the blaze.

When the rising shape becomes less sharp in the edge portion of the blaze as described above, the optical characteristics of the optical lens are degraded, and the diffraction efficiency in particular is deteriorated. Further, when the consideration is given to the product

quality, the aforementioned disadvantage will cause product value to be reduced. To improve the diffraction efficiency of the optical lens and to enhance product value, the rising shape in the edge portion of the blaze must be made as sharp as possible.

In the meantime, the electron beam applied in the form of having a large beam diameter has the disadvantage of being seriously subjected to external disturbances. Further, in the commonly employed electron beam depicting apparatus based on spot beam method and others, the diameter of electron beam is set within the range from several nanometers to several tens of nanometers. If the diameter of electron beam is made larger, aberration or other defect will occur, and practical utility will be reduced.

To solve such a problem, the following technique can be considered: When the dose of electron beam is changed from the first dose to the second dose (where the difference between the first and second doses is equivalent to the dose of minimum adjustment unit based on the analog-to-digital converter minimum clock) while using a small-diameter beam for the purpose of patterning the sloped surface of the blaze, a sloped portion of different doses is provided, where the portion formed by both the first and second doses is

present between the portion of the substrate formed by the

first dose and that formed by the second dose. After

development, the sloped portion of different doses is formed

to have a height intermediate between the height of the

portion of the substrate formed by the first dose and that of

the portion formed by the second dose, with the result that

the sloped portion of the blaze is made smooth and the rising

portion of the edge is made sharp.

However, as described above, this is accompanied by the

problem of requiring a great amount of time if both the

sloped portion and edge of the blaze and the edge--the entire

blaze--are formed using a small-diameter beam.

In order to get a smooth sloped portion of the blaze,

it is necessary in practice to use a large-diagram beam. By

contrast, a small-diameter beam must be used to get a sharp

rising portion of the blaze edge. The prior art, however,

has failed to get a smooth sloped portion of the blaze and a

sharp rising portion of the blaze edge and to reduce the

overall blaze patterning time, at the same time.

SUMMARY OF THE INVENTION

To overcome the abovementioned drawbacks in

conventional electron beam depicting methods and apparatus,

it is an object of the present invention to provide electron

beam depicting method and apparatus capable of getting a

smooth sloped portion of the blaze and a sharp rising portion

of the blaze edge using a small-diameter beam, and reducing

the overall blaze patterning time, at the same time.

Accordingly, to overcome the cited shortcomings, the

abovementioned object of the present invention can be

attained by electron beam depicting methods and apparatus

described as follow.

(1) An electron beam depicting method for depicting a

predetermined pattern on a substrate, comprising the steps

of: acquiring shape data of the predetermined pattern;

generating a first input signal for deflecting an electron

beam emitted from an electron gun in a main-scanning

direction, and a second input signal for deflecting the

electron beam emitted from the electron gun in a sub-scanning

direction, based on the shape data of the predetermined

pattern; adjusting an alternating bias signal, having a

specific frequency, according to the shape data of the

predetermined pattern; superposing the alternating bias

signal on the second input signal; and deflecting the

electron beam emitted from the electron gun in the sub-

scanning direction according to the second input signal on

which the alternating bias signal is superposed, while
scanning the electron beam emitted from the electron gun by
deflecting it in a main-scanning direction.

(2) The electron beam depicting method of item 1, wherein an
amplitude of the alternating bias signal is adjusted in
response to the shape data of the predetermined pattern in
the adjusting step.

(3) The electron beam depicting method of item 1, wherein a
structure of the predetermined pattern includes a plurality
of edge portions.

(4) The electron beam depicting method of item 1, wherein the
predetermined pattern is a diffraction structure constituted
by a plurality of blazed diffraction gratings; and wherein
the alternating bias signal is adjusted corresponding to a
sloped area and an edge portion of each of the blazed
diffraction gratings in the adjusting step.

(5) The electron beam depicting method of item 4, wherein an
amplitude of the alternating bias signal is adjusted to a
first amplitude value in a vicinity of the edge portion,
while the amplitude of the alternating bias signal is
adjusted to a second amplitude value in a vicinity of a
center of the sloped area; and wherein the first amplitude
value is smaller than the second amplitude value.

(6) The electron beam depicting method of item 1, further comprising the step of; controlling a scanning pitch in the sub-scanning direction of the electron beam in response to an amplitude of the alternating bias signal.

(7) The electron beam depicting method of item 1, wherein a depicted surface of the substrate is a curved surface.

(8) A method for manufacturing a mother die of a metallic mold utilized for molding an optical element, comprising the steps of: forming a resist film on a substrate; acquiring shape data of a predetermined pattern; generating a first input signal for deflecting an electron beam emitted from an electron gun in a main-scanning direction, and a second input signal for deflecting the electron beam emitted from the electron gun in a sub-scanning direction, based on the shape data of the predetermined pattern; adjusting an alternating bias signal, having a specific frequency, according to the shape data of the predetermined pattern; superposing the alternating bias signal on the second input signal; scanning the electron beam emitted from the electron gun by deflecting it in a main-scanning direction, while scanning the electron beam, emitted from the electron gun, by deflecting it in the sub-scanning direction according to the second input signal on which the alternating bias signal is superposed, so that

the electron beam irradiated onto the substrate depicts the predetermined pattern; and developing the resist film on the substrate depicted in the scanning step, so as to acquire the mother die having a predetermined structure.

(9) The method of item 8, further comprising the step of: etching the substrate developed in the developing step.

(10) A mother die of a metallic mold utilized for molding an optical element, the mother die being manufactured by a method comprising the steps of: forming a resist film on a substrate; acquiring shape data of a predetermined pattern; generating a first input signal for deflecting an electron beam emitted from an electron gun in a main-scanning direction, and a second input signal for deflecting the electron beam emitted from the electron gun in a sub-scanning direction, based on the shape data of the predetermined pattern; adjusting an alternating bias signal, having a specific frequency, according to the shape data of the predetermined pattern; superposing the alternating bias signal on the second input signal; scanning the electron beam emitted from the electron gun by deflecting it in a main-scanning direction, while scanning the electron beam, emitted from the electron gun, by deflecting it in the sub-scanning direction according to the second input signal on which the

alternating bias signal is superposed, so that the electron

beam irradiated onto the substrate depicts the predetermined

pattern; and developing the resist film on the substrate

depicted in the scanning step, so as to acquire the mother

die having a predetermined structure.

(11) The mother die of item 10, the method further comprising

the step of: etching the substrate developed in the

developing step.

(12) A method for manufacturing metallic mold utilized for

molding an optical element, comprising the steps of: forming

a resist film on a substrate; acquiring shape data of a

predetermined pattern; generating a first input signal for

deflecting an electron beam emitted from an electron gun in a

main-scanning direction, and a second input signal for

deflecting the electron beam emitted from the electron gun in

a sub-scanning direction, based on the shape data of the

predetermined pattern; adjusting an alternating bias signal,

having a specific frequency, according to the shape data of

the predetermined pattern; superposing the alternating bias

signal on the second input signal; scanning the electron beam

emitted from the electron gun by deflecting it in a main-

scanning direction, while scanning the electron beam, emitted

from the electron gun, by deflecting it in the sub-scanning

direction according to the second input signal on which the alternating bias signal is superposed, so that the electron beam irradiated onto the substrate depicts the predetermined pattern; developing the resist film on the substrate depicted in the scanning step, so as to acquire a mother die having a predetermined structure; and applying an electroforming processing to the mother die having the resist film developed in the developing step, so as to form the metallic mold on which the predetermined structure is transferred.

(13) The method of item 12, further comprising the step of: etching the substrate developed in the developing step.

(14) A metallic mold utilized for molding an optical element, the metallic mold being manufactured by a method comprising the steps of: forming a resist film on a substrate; acquiring shape data of a predetermined pattern; generating a first input signal for deflecting an electron beam emitted from an electron gun in a main-scanning direction, and a second input signal for deflecting the electron beam emitted from the electron gun in a sub-scanning direction, based on the shape data of the predetermined pattern; adjusting an alternating bias signal, having a specific frequency, according to the shape data of the predetermined pattern; superposing the alternating bias signal on the second input signal; scanning

the electron beam emitted from the electron gun by deflecting
it in a main-scanning direction, while scanning the electron
beam, emitted from the electron gun, by deflecting it in the
sub-scanning direction according to the second input signal
on which the alternating bias signal is superposed, so that
the electron beam irradiated onto the substrate depicts the
predetermined pattern; developing the resist film on the
substrate depicted in the scanning step, so as to acquire a
mother die having a predetermined structure; and applying an
electroforming processing to the mother die having the resist
film developed in the developing step, so as to form the
metallic mold on which the predetermined structure is
transferred.

(15) The metallic mold of item 14, the method further
comprising the step of: etching the substrate developed in
the developing step.

(16) A method for manufacturing an optical element,
comprising the steps of: forming a resist film on a
substrate; acquiring shape data of a predetermined pattern;
generating a first input signal for deflecting an electron
beam emitted from an electron gun in a main-scanning
direction, and a second input signal for deflecting the
electron beam emitted from the electron gun in a sub-scanning

direction, based on the shape data of the predetermined

pattern; adjusting an alternating bias signal, having a

specific frequency, according to the shape data of the

predetermined pattern; superposing the alternating bias

signal on the second input signal; scanning the electron beam

emitted from the electron gun by deflecting it in a main-

scanning direction, while scanning the electron beam, emitted

from the electron gun, by deflecting it in the sub-scanning

direction according to the second input signal on which the

alternating bias signal is superposed, so that the electron

beam irradiated onto the substrate depicts the predetermined

pattern; developing the resist film on the substrate depicted

in the scanning step, so as to acquire a mother die having a

predetermined structure; applying an electroforming

processing to the mother die having the resist film developed

in the developing step, so as to form a metallic mold onto

which the predetermined structure is transferred; and molding

the optical element having the predetermined structure by

means of the metallic mold.

(17) The method of item 16, further comprising the step of:

etching the substrate developed in the developing step.

(18) An optical element manufactured by a method comprising

the steps of: forming a resist film on a substrate; acquiring

shape data of a predetermined pattern; generating a first

input signal for deflecting an electron beam emitted from an

electron gun in a main-scanning direction, and a second input

signal for deflecting the electron beam emitted from the

electron gun in a sub-scanning direction, based on the shape

data of the predetermined pattern; adjusting an alternating

bias signal, having a specific frequency, according to the

shape data of the predetermined pattern; superposing the

alternating bias signal on the second input signal; scanning

the electron beam emitted from the electron gun by deflecting

it in a main-scanning direction, while scanning the electron

beam, emitted from the electron gun, by deflecting it in the

sub-scanning direction according to the second input signal

on which the alternating bias signal is superposed, so that

the electron beam irradiated onto the substrate depicts the

predetermined pattern; developing the resist film on the

substrate depicted in the scanning step, so as to acquire a

mother die having a predetermined structure; applying an

electroforming processing to the mother die having the resist

film developed in the developing step, so as to form a

metallic mold onto which the predetermined structure is

transferred; and molding the optical element having the

predetermined structure by means of the metallic mold.

(19) The optical element of item 18, the method further comprising the step of: etching the substrate developed in the developing step.

(20) An electron beam depicting apparatus for depicting a predetermined pattern on a substrate by irradiating an electron beam onto the substrate, comprising: an electron-beam irradiating section to irradiate the electron beam onto the substrate; an electron-beam deflecting section to deflect the electron beam irradiated from the electron-beam irradiating section; a storage section to store shape data of the predetermined pattern; and a controlling section to control the electron-beam irradiating section and the electron-beam deflecting section, based on the shape data of the predetermined pattern stored in the storage section; wherein the controlling section includes: a first-signal generating circuit to generate a first signal for deflecting the electron beam in a main-scanning direction; a second-signal generating circuit to generate a second signal for deflecting the electron beam in a sub-scanning direction; an alternating-bias signal adjusting circuit to adjust an alternating bias signal having a specific frequency; and an alternating-bias signal superposing circuit to superpose the alternating bias signal on the second signal.

(21) The electron beam depicting apparatus of item 20,

wherein the shape data of the predetermined pattern, stored

in the storage section, include dose distributing

information, which are defined as dose distributions

corresponding to each of scanning positions on the substrate.

(22) The electron beam depicting apparatus of item 20,

wherein the alternating-bias signal adjusting circuit adjusts

an amplitude of the alternating bias signal in response to

the shape data of the predetermined pattern.

(23) The electron beam depicting apparatus of item 22,

wherein the predetermined pattern is a diffraction structure

constituted by a plurality of blazed diffraction gratings;

and wherein the alternating-bias signal adjusting circuit

adjusts the alternating bias signal so that the amplitude of

the alternating bias signal varies corresponding to a sloped

area and an edge portion of each of the blazed diffraction

gratings.

(24) The electron beam depicting apparatus of item 23,

wherein the alternating-bias signal adjusting circuit adjusts

the amplitude of the alternating bias signal to a first

amplitude value in a vicinity of the edge portion, while the

alternating-bias signal adjusting circuit adjusts the

amplitude of the alternating bias signal to a second

amplitude value in a vicinity of a center of the sloped area;
and wherein the first amplitude value is smaller than the
second amplitude value.

(25) The electron beam depicting apparatus of item 24,
wherein the controlling section also adjusts a deflection
pitch, with which the electron beam is deflected in the sub-
scanning direction according to the second signal,
corresponding to the amplitude of the alternating bias signal
adjusted by the alternating-bias signal adjusting circuit.

Further, to overcome the abovementioned problems, other
electron beam depicting methods, embodied in the present
invention, will be described as follow:

(26) An electron beam depicting method, characterized in
that,

in the electron beam depicting method for depicting a
predetermined pattern on a base material, by scanning an
electron beam in a main-scanning direction onto the base
material being an object under depicting and by repeating the
main-scanning operation in a sub-scanning direction, the
method includes:

an acquiring step for acquiring shape data of the
predetermined pattern;

a signal generating step for generating a first input signal for deflecting an emitted electron beam in the main-scanning direction, and a second input signal for deflecting the emitted electron beam in a sub-scanning direction, based on the shape data of the predetermined pattern;

a frequency adjusting step for adjusting an frequency signal, having a specific frequency and serving as an alternating bias signal, according to the shape data of the predetermined pattern;

a superposing step for superposing the frequency signal on the second input signal;

a scanning step for scanning the emitted electron beam in the main-scanning direction by deflecting it according to the first input signal, and scanning the emitted electron beam in the sub-scanning direction by deflecting it according to the second input signal.

(27) The electron beam depicting method, described in item 26, characterized in that

an amplitude of the frequency signal is adjusted in response to the shape data of the predetermined pattern

(28) The electron beam depicting method, described in item 26 or 27, characterized in that

a structure of the predetermined pattern includes a plurality of edge portions.

(29) The electron beam depicting method, described in item 26 or 27, characterized in that

the predetermined pattern is a diffraction structure constituted by a plurality of blazed diffraction gratings; and the frequency signal is adjusted corresponding to a sloped area and an edge portion of each of the blazed diffraction gratings.

(30) The electron beam depicting method, described in item 29, characterized in that

the amplitude of the frequency signal is adjusted to a small value in respect to a vicinity of the edge portion, compared to that at a center of the sloped area.

(31) The electron beam depicting method, described in anyone of items 27 - 29, characterized in that the method further includes:

a scanning pitch adjusting step for adjusting a scanning pitch in respect to the sub-scanning direction of said electron beam.

(32) The electron beam depicting method, described in anyone of items 26 - 31, characterized in that

a surface of the base material, being the object under depicting, has a curved surface.

(33) A manufacturing method of a mother die, characterized in that,

in the manufacturing method of the mother die for manufacturing the mother die of a metallic mold utilized for molding an optical element by using the base material depicted by means of the electron beam depicting method described in anyone of items 26 - 32, the method includes:

a resist film forming step for forming a resist film on the base material before depicting on the base material;

a developing step for developing the depicted resist film on the base material, so as to acquire the mother die having a predetermined structure.

(34) The manufacturing method of a mother die, described in item 33, characterized in that the method further includes:

an etching step for applying an etching processing to the base material developed in the developing step.

(35) A mother die, characterized in that

the mother die is manufactured by the manufacturing method of the mother die, described in item 33 or 34.

(36) A manufacturing method of a metallic mold, characterized in that the method includes:

an electroforming step for conducting electroforming processing by using the mother die described in item 35 to acquire the metallic mold onto which the predetermined structure on the mother die is transferred.

(37) A metallic mold, characterized in that

the metallic mold is manufactured by the manufacturing method of the metallic mold, described in item 36.

(38) An optical element, characterized in that

the optical element is molded by the metallic mold, described in item 37.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

Fig. 1 is a drawing representing the pattern formed on the one side of this substrate and its detailed configuration subsequent to its development;

Fig. 2 is an explanatory drawing for explaining the detail of a main part of the substrate shown in Fig. 1;

Fig. 3 is a drawing representing the overall configuration of an electron beam depicting apparatus;

Fig. 4 is an explanatory drawing for explaining a measuring principle of a measuring device equipped in an electron beam depicting apparatus;

Fig. 5(A), Fig. 5(B) and Fig. 5(C) are explanatory drawings for explaining a method for measuring a surface height of the substrate;

Fig. 6 is an explanatory drawing for explaining a relationship between a light emission and a light reception of a measuring device equipped in an electron beam depicting apparatus shown in Fig. 1;

Fig. 7 is a characteristic graph showing a relationship between a height of the substrate and output signals from a light receiving section of a measuring device;

Fig. 8(A) and Fig. 8(B) are explanatory drawings showing the substrate to be depicted by an electron beam depicting apparatus shown in Fig. 1, and Fig. 8(C) is an explanatory drawing for explaining a depicting principle of it;

Fig. 9 is an explanatory drawing for explaining a beam-waist of an electron beam;

Fig. 10 is a functional block diagram showing details of a controlling system of an electron beam depicting apparatus shown in Fig. 1;

Fig. 11 is an explanatory drawing for explaining a
configuration of peripheral sections including a sub-
deflecting section of an electron beam depicting apparatus
shown in Fig. 1;

Fig. 12(A) is an explanatory drawing for explaining a
conventional depicting method, and Fig. 12(B) is an
explanatory drawing for explaining a depicting method
performed by an electron beam depicting apparatus shown in
Fig. 1;

Fig. 13(A) and Fig. 13(B) are explanatory drawings for
explaining a process of superposing an alternating bias
signal onto a deflection signal by means of an alternating-
bias signal superposing circuit at a sub-deflecting section
of an electron beam depicting apparatus shown in Fig. 1;

Fig. 14(A) is an explanatory drawing for explaining a
depicting area in a conventional scanning operation of an
electron beam, and Fig. 14(B) is an explanatory drawing for
explaining a depicting area in a scanning operation of an
electron beam, performed by an electron beam depicting
apparatus shown in Fig. 1;

Fig. 15 is a flowchart for explaining a processing flow
of a controlling section when blazed gratings are depicted by
an electron beam depicting apparatus shown in Fig. 1;

Fig. 16 is an explanatory drawing for explaining a processing of a controlling section when blazed gratings are depicted by an electron beam depicting apparatus shown in Fig. 1;

Fig. 17(A), Fig. 17(B), Fig. 17(C), Fig. 17(D), Fig. 17(E), and Fig. 17(F) are explanatory drawings for explaining an overall processing procedure when forming a metallic mold for molding an optical element by employing the substrate;

Fig. 18(A) and Fig. 18(B) are explanatory drawings for explaining an overall processing procedure when molding an optical element by employing the metallic mold; and

Fig. 19(A) and Fig. 19(B) are cross sectional views of slope surfaces of the blaze shape, showing comparison between a finished surface processed by conventional method and that by a method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, the preferred embodiments of an electron beam depicting method embodied in the present invention will be detailed in the following.

[CONFIGURATION OF SUBSTRATE]

In the first place, the following shows the configuration of the substrate to be formed by the electron

beam depicting apparatus: The following description of the
present embodiment will take examples of the cases where a
diffraction structure of blaze shape is formed while a circle
is formed on one surface of the substrate having a curved
surface. It should be noted that the present invention is
not restricted thereto; the surface of the substrate can be a
plane surface.

Fig. 1 is a drawing representing the pattern formed on
the one side of this substrate and its detailed configuration
subsequent to its development. As shown in Fig. 1, a circle
is formed on one side of the substrate 2 as an example of the
pattern. When the portion E as part of the formed portion is
enlarged, it can be seen that a diffraction structure made up
of a plurality of blazes 3 is formed. The blaze 3 makes up a
slope 3b (sloped surface) and side wall 3a (edge). The slope
3b is created in a curved surface circumferentially in a
plurality of steps.

To put it in greater details, the substrate 2 has a
curved surface 2a created on at least one surface, as shown
in Fig. 2, and a diffraction grating is tilted to form a
blaze for each pitch L1. A side wall 3a rising from the
curved surface 2a at the position separating between two
pitches, a slope 3b created between adjacent side walls 3a,

and a groove 3c formed in the boundary between the side wall

3a and slope 3b are formed for at least one pitch of this

diffraction grating.

The slope 3b is configured in such a way that one end

is in contact with the base of one end of the side wall 3a

and the other end with that of the other end of the side wall

3a. As will be described later, the diffraction grating

comprising a plurality of blazes 3 is formed by the step of

exposing a coating agent (a resist) applied to the curved

surface 2a through an electron beam depicting apparatus, and

the step of development. The slope 3b of the blaze 3 is

provided with a smooth slope through exposure by the electron

beam depicting apparatus to be described later. The side

wall 3a and groove 3c, namely the edge, are provided with a

sharp rising configuration through exposure by the electron

beam depicting apparatus.

[CONFIGURATION OF AN ELECTRON BEAM DEPICTING APPARATUS]

The following describes the specific configuration of

the electron beam depicting apparatus used for patterning of

the aforementioned substrate:

Fig. 3 is a drawing representing the overall

configuration of an electron beam depicting apparatus. As

shown in Fig. 3, in the electron beam depicting apparatus 1,

a large-current, high-resolution electron beam probe is

formed and is operated to scan the substrate 2 as an exposure

target at a high speed. The electron beam depicting

apparatus 1 includes: an electron gun 12 as an electron beam

application means for forming a high-resolution electron beam

probe, generating en electronic beam and applying beams to

the target; a slit 14 for allowing the electron beam from

this electron gun 12 to pass through; an electron lens 16 for

controlling the focal position of the electron beam passing

through the slit 14 with respect to the substrate 2; an

aperture 18 arranged along the path for outgoing electron

beam; a deflector 20 for controlling the scan position on the

substrate 2 as a target by deflecting the electron beam; and

a correction coil 22 for correcting deflection. These

components are arranged in a lens barrel 10 and are kept in a

vacuum state when the electron beam is applied.

Further, the electron beam depicting apparatus 1

includes; a X-Y-Z stage 30 for mounting the substrate as an

exposure target; a loader 40 as a transport means for

transporting the substrate 2 to the mounting position on this

X-Y-Z stage 30; a measuring apparatus 30 as a measuring means

for measuring the reference point on the surface of the

substrate 2 on the X-Y-Z stage 30; a stage drive device 50 as

a drive means for driving the X-Y-Z stage 30; a stage driver
50 as a drive means for driving the loader; a vacuum creating
device 70 for creating a vacuum in the lens barrel 10 and
enclosure 11 through evacuation; and a control circuit 100 as
a control means for controlling the above.

The electron lens 16 is designed in such a way that a
plurality of electronic lenses are generated by supplying
electric current to the coils 17a, 17b and 17c arranged apart
from one another at several places along the height, and the
focal position and width (width of beam waste) of the
electron beam are adjusted by controlling the aforementioned
current value.

The measuring device 80 includes: a first laser length-
measuring machine 82 for measuring the substrate 2 by
applying laser to the substrate 2; a first beam receiver 84
for receiving the laser beam (first applied beam) emitted
from the first laser length-measuring machine 82 when it has
hit the substrate 2 and is reflected thereby; a second laser
length-measuring machine 86 where the beam is applied from
the angle different from that for the aforementioned first
laser length-measuring machine 82; and a second beam receiver
88 for receiving the laser beam (second applied light)
emitted by the aforementioned second laser length-measuring

machine 86 when it has hit the substrate 2 and is reflected
thereby.

The stage drive device 50 includes: an X direction
drive mechanism 52 for driving the X-Y-Z stage 30 in the X
direction; a Y direction drive mechanism 54 for driving the
X-Y-Z stage 30 in the Y direction; a Z direction drive
mechanism 56 for driving the X-Y-Z stage 30 in the Z
direction; and a θ direction drive mechanism 58 for driving
the X-Y-Z stage 30 in the θ direction. It is also possible
to make such arrangements that an α direction drive
mechanism capable of rotation in the α direction about the Y
axis, and a β direction drive mechanism capable of rotation
in the β direction about the X axis are provided in addition
to the aforementioned ones, to ensure that pitching, yoking
and rolling of the stage can be performed. This arrangement
allows the X-Y-Z stage 30 to be moved in three dimensions and
permits alignment to be performed.

The control circuit 100 includes: an electron gun power
supply 102 for supply electric power to the electron gun 12;
an electron gun controller 104 for regulating and controlling
the current and voltage of the electron gun power supply 102;
a lens power supply 106 for driving the electron lens 16

(each of a plurality of electronic lens); and a lens

controller 108 for regulating and controlling the current

corresponding to each electron lens at the lens power supply

106. The electron gun power supply 102 has a digital-to-

analog converter (not illustrated) for supply power to the

electron gun 12. The dose of the electron beam applied from

the electron gun 12 can be regulated by the electron gun

controller 104 regulating and controlling the current and

voltage of the digital-to-analog converter (not illustrated).

Thus, the dose of the minimum regulation unit of the electron

beam depicting apparatus is determined by the minimum clock

of this digital-to-analog converter.

The control circuit 100 further includes: a coil

controller 110 for controlling the correction coil 22; a

molding deflector 112a for carrying out deflection in the

molding direction by the deflector 20; a sub-deflector 112b

for carrying out deflection in the sub-scanning direction by

the deflector 20; a main deflector 112c for carrying out

deflection in the main scanning direction by the deflector

20; a high-speed digital-to-analog converter 114a for

converting a digital signal from digital to analog signal to

control the molding deflector 112a; a high-speed digital-to-

analog converter 114b for converting a digital signal from

digital to analog signal to control the sub-deflector 112b;

molding deflector 112a; and a high-precision digital-to-

analog converter 114c for converting a digital signal from

digital to analog signal to control the main deflector 112c.

The control circuit 100 further includes: a position

error correction circuit 116 for correcting the positional

error in the deflector 20, i.e. promoting correction of the

positional error by supplying a position error correction

signal to the high-speed digital-to-analog converters 114a

and 114b and high-precision digital-to-analog converter 114c

or correcting the positional error through the correction

coil 22 by supplying the aforementioned signal to the coil

controller 110; a field control circuit 118 for controlling

the electron beam field by controlling the high-speed

digital-to-analog converters 114a and 114b and high-precision

digital-to-analog converter 114c; and a pattern generation

circuit 120 for forming the pattern on the substrate 2.

Incidentally, the pattern generation circuit 120 generates a

predetermined pattern according to the information on the

various pattern configurations loaded in the memory 160.

This arrangement allows the data on the predetermined pattern

to be acquired.

The control circuit 100 further includes: a first laser drive control circuit 130 for controlling the travel of the laser application position by vertical and horizontal travel of the first laser length-measuring machine 82 and the drive of the angles such as laser application angle; a second laser drive control circuit 132 for controlling the travel of the laser application position by vertical and horizontal travel of the second laser length-measuring machine 86 and the drive of the angles such as laser application angle; a first laser output control circuit 134 for regulating and controlling the output of the laser beam (laser beam intensity) by the first laser length-measuring machine 82; a second laser output control circuit 136 for regulating and controlling the output of the laser beam by the second laser length-measuring machine 86; a first measurement calculator 140 for calculating the result of measurements base on the reception by the first beam receiver 84; and a second measurement calculator 142 for calculating the result of measurements based on the reception by the second beam receiver 88.

The control circuit 100 further includes: a stage control circuit 150 for controlling the stage drive device 50; a loader control circuit 152 for controlling a loader driver 60; a mechanism control circuit 154 for controlling

the first laser drive control circuits 130 and 132, the

second laser output control circuits 134 and 136, the first

and second measurement calculators 140 and 142, the stage

control circuit 150, and the loader control circuit 152; a

vacuum control circuit 156 for controlling the vacuum

creation and evacuation of the vacuum creating device 70; a

measurement information input section 158 for inputting the

measurement information; a memory 160 as a memory means for

storing the inputted information and other multiple

information items; a program memory 162 for memorizing the

control program for various type of controls; and a

controller 170, created, for example, by the CPU, for

controlling the aforementioned items.

The electron beam depicting apparatus 1 is designed in

such a way that various types of command operations such as

analog/digital mode selection and selection from a plurality

of the patterns of basic configuration can be performed in

the so-called "operation system" or "operation means"

including the measurement information input section 158.

In the electron beam depicting apparatus 1 configured

in the aforementioned arrangement, when the substrate 2

carried by the loader 40 is mounted on the X-Y-Z stage 30,

electron beam is irradiated from the electron gun 12 after

air and dust in the lens barrel 10 and enclosure 11 is
removed by the vacuum creating device 70.

The electron beam applied from the electron gun 12 is
deflected by the deflector 20 through the electron lens 16.
The deflected electron beam B (hereinafter the electron beam
having passed through the electron lens 16 may be referred to
as "electron beam B") is applied to the surface of the
substrate 2 on the X-Y-Z stage 30, for example, the
patterning position on the curved surface 2a (curve), whereby
patterning is carried out.

In this case, the patterning position (at least the
position along the height out of the patterning positions on
the substrate 2) or the position of the reference point to be
described later is measured by the measuring device 80. The
control circuit 100 regulates and controls the current values
flowing through the coils 17a, 17b and 17c of the electron
lens 16 according to the result of measurement, thereby
controlling the position of the focal depth of the electron
beam B, i.e. the focal position, and traveling control is
provided so that the focal position will be the
aforementioned patterning position.

Based on the result of measurement, the control circuit
100 controls the stage drive device 50, thereby moving the X-

Y-Z stage 30 in such a way that the focal position of the
electron beam B will be the aforementioned patterning
position.

Control of electron beam and/or X-Y-Z stage 30 may be
employed in this example.

(Measuring Device)

The following describes the measuring device 80 with
reference to Fig. 4: To put it in greater details, the
measuring device 80 contains the first laser length-measuring
machine 82, first beam receiver 84, second laser length-
measuring machine 86 and second beam receiver 88, as shown in
Fig. 4.

The first light beam S1 is applied to the substrate 2
from the direction crossing the electron beam by the first
laser length-measuring machine 82. The first light intensity
distribution is detected by reception of the first light beam
S1 passing through the substrate 2.

In this case, as shown in Fig. 4, the first light beam
S1 is reflected by the flat portion 2b of the substrate 2,
and therefore the position on the flat portion 2b of the
substrate 2 (height) can be measured and calculated according
to the first beam strength distribution. In this case,

however, the position on the curved surface 2a of the
substrate 2 (height) can be measured and calculated.

In this example, the second laser length-measuring
machine 86 is further provided. In other words, the second
light beam S2 is applied to the substrate 2 from the
direction approximately orthogonal to the electron beam
different from the first light beam S1 by the second laser
length-measuring machine 86. The second light beam S2
passing through the substrate 2 is received by the pin hole
84 contained in the second beam receiver 88, whereby the
second beam strength distribution is detected.

In this case, as shown in Fig. 5(A), Fig. 5(B) and Fig.
5(C), the second light beam S2 passes over the curved surface
2a and therefore the position on the curved surface 2a
protruding from the flat portion 2b of the substrate 2
(height) is measured and calculated according to the second
beam strength distribution.

To put it more specifically, when the second light beam
S2 has passed through the specific height of the position (x,
y) on the curved surface 2a in the X-Y reference coordinate
system, the second light beam S2 hits the curve of the curved
surface 2a, as shown in Fig. 5(A), Fig. 5(B) and Fig. 5(C),
at this position (x, y), whereby scattered light SS1 and SS2

are produced, with the result that the intensity of this scatter light is reduced. In this manner, as shown in Fig. 6, the position is measured and calculated according to the second beam intensity distribution detected by the second beam receiver 88.

In this calculation, as shown in Fig. 6, the signal output Op of the second beam receiver 88 has a correlation between the signal output Op and substrate height as shown in the characteristic chart given in Fig. 7, and therefore this characteristic, i.e. the correlation table showing the relation of correlation is stored in the memory 160 of the control circuit 100 in advance, whereby the height position of the substrate can be calculated according to the signal output Op in the second beam receiver 88.

Thus, the focal position of the aforementioned beam is adjusted using this height position of the substrate as a position to be patterned, and patterning is carried out. (Overview of the Principle for calculating the patterning position)

The following outlines the principle for calculating the patterning position when patterning is carrying out:

As shown in Fig. 8(A) and Fig. 8(B), the substrate 2 is preferred to be formed by the optical element such as an

optical lens. It comprises the flat portion 2b having a

cross section of approximately planar surface and the curved

surface 2a protruding from the flat portion 2b. The curve of

this curved surface 2a is not limited to the spherical

surface; it can be a free curved surface that varies in all

directions of height including a non-spherical surface.

In such a substrate 2, a plurality of reference points,

e.g. three points P00, P01 and P02 on the substrate 2 are

determined in advance, before the substrate 2 is mounted on

the X-Y-Z stage 30, and these positions are measured (first

measurement). This arrangement allows the X axis to be

defined by the reference points P00 and P01, and Y axis by

the reference points P00 and P02, whereby the first reference

coordinate system in the 3-D coordinate system is calculated.

Here the height position in the first refrigerator coordinate

system is assumed as Ho (x, y) (first height position). This

arrangement allows the thickness of the substrate 2 to be

calculated.

After the substrate 2 has been mounted on the X-Y-Z

stage 30, the same steps are taken. To put it another way,

as shown in Fig. 8(A), a plurality of reference points, e.g.

three points P10, P11 and P12 on the substrate 2 are

determined in advance, and these positions are measured

(second measurement). This arrangement allows the X axis to
be defined by the reference points P10 and P11, and Y axis by
the reference points P10 and P12, whereby the second
reference coordinate system in the 3-D coordinate system is
calculated.

Using the reference points P00, P01, P02, P10, P11 and
P12, a coordinate conversion matrix or the like for
converting the first reference coordinate system into the
second one is calculated. This coordinate conversion matrix
is employed to calculate the height position Hp (x, y)
(second height position) corresponding to the aforementioned
Ho (x, y) in the second reference coordinate system. Using
this position as the optimum focus position, i.e. position to
be patterned, the focal position of electron beam is
adjusted. This arrangement allows the thickness distribution
of the aforementioned substrate 2 to be corrected.

The aforementioned second measurement can be made by
the measuring device 80 as a first measuring means of the
electron beam depicting apparatus 1.

The first measurement must be measured by another
measuring device in a separate position. Such a measuring
device for measuring the reference point in advance before
the substrate 2 is mounted on the substrate 2 includes the

measuring device (second measuring means) having exactly the same configuration as that of the aforementioned measuring device 80, and this can be adopted.

In this case, the result of measurement by the measuring device is inputted, for example, by a measurement information input section 158 shown in Fig. 3, or is transferred as data through the network (not illustrated) connected to the control circuit 100 and is stored in the memory 160. Needless to say, this measuring device may not be necessary.

In the manner described above, the position to be patterned is calculated and the focal position of electron beam is controlled, whereby patterning is carried out.

To put it more specifically, as shown in Fig. 8(C), the focal position of the focal depth FZ of electron beam (beam waist BW = position of the smallest beam diameter) is adjusted and controlled to the position to be patterned in one field (m = 1) of the unit space in the 3-D coordinate system. (This control, as described above, is performed by the adjustment of the current value by the electron lens 16 and/or the drive control of the X-Y-Z stage 30). In this example, the field is set in such a way that height of one field is longer than the focal depth FZ, without the present

invention being restricted thereto. Here the focal depth FZ

denotes the height of the range where the beam waist BW is

valid, in the electron beam B applied through the electron

lens 16, as shown in Fig. 9. Incidentally, as described

above, the width of the beam waist BW is adjusted by

controlling the currents flowing through the coils 17a, 17b,

17c, etc. of the electron lens 16. In the case of the

electron beam B, the D/f is about 0.01 assuming the width D

of the electron lens 16 and depth f from the electron lens 16

to the beam waist BW, as shown in Fig. 9. For example, the

resolution is about 50 nanometers and the focal depth is

several tens of microns.

Referring to Fig. 8(C), patterning is carried out in

one field when scanning in the X direction is carried out

gradually while shifting in the Y direction within one field.

If there is any area in one field where patterning is not

performed, patterning is carried out by similar scanning for

this area through movement in the Z direction under the

control of the focal position as described above.

After patterning in one field, in other fields such as

the field of m = 2 or m = 3 as well, processing of patterning

is applied on a real-time basis while measurement and

calculation of the position to be patterned are performed, in

the same manner as above. When all patterning operations

have been completed for all the areas to be patterned,

processing of patterning on the surface of the substrate 2

terminates.

In this example, the area to be patterned is assumed as

a layer to be patterned, and the portion corresponding to the

curve of the curved surface 2a in this layer as a surface to

be patterned.

The processing programs for handling various

operations, measurements and controls as described above are

loaded in the program memory 162 as control programs in

advance.

(Control System)

Referring to Fig. 10, the control system in the

electron beam depicting apparatus 1 will be described:

As shown in Fig. 10, the memory 160 stores a shape

memory table 161. This table contains a dose distribution

information 161a for previously defining the distribution of

the dose corresponding to each scan position of the side wall

3a and slope 3b of the blaze 3 formed on the curved surface

2a of the substrate 2, and a beam diameter information 161b

for previously defining the beam diameter corresponding to

each scan position of the side wall 3a and slope 3b of the

blaze 3.

The program memory 162 contains a processing program

163a for the controller 170 to apply processing to be

described later, and other processing programs 163c.

Incidentally, a setting device 181 shown in Fig. 10 is

used to set the dose distribution information 161a and beam

diameter information 161b stored in the shape memory table

161 of the memory 160. A display device 182 displays dose

distribution information and others for each scanning line.

In such a configuration, the controller 170 calculates

the dose corresponding to each scan position of the side wall

3a and slope 3b of the blaze 3, based on the dose

distribution information 161a and beam diameter information

161b stored in the shape memory table 161 of the memory 160,

according to the processing program 163c. The controller 170

also calculates probe current, scanning pitch and diameter of

electron beam B.

The controller 170 controls the electron gun controller

104, field control circuit 118 and lens controller 108,

according to the calculated probe current, scanning pitch and

diameter of the electron beam B. This arrangement optimizes

the probe current, scanning pitch and diameter of electron

beam B at the time of patterning. The desired form can be

obtained after the patterned substrate 2 has been developed.

The diameter of the electron beam B can also be

adjusted by changing the size of the opening of the aperture

18.

(Alternating-bias Signal Superposing Circuit)

Referring the Fig. 11, the following describes a sub-

deflector 112b as a portion characteristic of the present

invention or a alternating bias signal superposing circuit

constituting the sub-deflector 112b, to put it in greater

details.

As shown in Fig. 11, the sub-deflector 112b is

generated by the field control circuit 118. It comprises:

input/output circuits 113a and 113b used to ensure that the

deflection signal on X direction defined in the present

apparatus for example, or the deflection signal of phase "+"

or "-" on X direction, to put it in greater details, is

outputted into each of deflecting plates 21a and 21b arranged

opposite to the deflector 20, according to the deflection

signal entered from the high-speed digital-to-analog

converter 114b; input/output circuits 113d and 113d used to

ensure that the deflection signal on the Y direction

orthogonal to the X direction, or the deflection signal of

phase "+" or "-" on Y direction, to put it in greater

details, is outputted into each of deflecting plates 21c and

21d arranged opposite to the deflector 20; and a alternating

bias signal superposing circuit for superposing an

alternating bias signal having a specific frequency (e.g.

high frequency signal) on the signal that is inputted into

the circuits of either phase (input/output circuits 113b and

113d having the negative phase in this example), out of these

input/output circuit's 113a, 113b, 113c and 114d.

Incidentally, the input/output circuits 113b and 113d are

inputted from the high-speed digital-to-analog converter

114b. The deflection signal of the electron beam B having

passed through the input/output circuits 113a and 113c and

the alternating bias signal from the alternating bias signal

superposing circuit 115 are superposed on each other through

processing of addition, and their polarity is reversed at the

same time. Further, these input/output circuits 113b and

113d can be formed by a normal operation circuit.

As described above, the electron beam applied from the

electron gun 12 is deflected by the deflector 20 through the

electron lens 16, and the deflected electron beam B is

applied to the position to be patterned on the surface of the

substrate 2 on the X-Y-Z stage 30, e.g. on the curved surface

2a, whereby patterning is carried out by electron beam. In
this case, when a blaze-shaped diffraction structure is
formed on the curved surface 2a of the substrate 2,
patterning by electron beam described below will be carried
out by the sub-deflector 112b having the aforementioned
configuration under the control by the controller 170:

In the following description, it should be understood
that "the X direction defined in the present apparatus" and
"the Y direction orthogonal to the X direction" agree with
the main scanning direction and sub-scanning direction of the
electron beam B, respectively. This allows the deflection
signal on X direction to correspond to the "first input
signal" of the present invention. The deflection signal on Y
direction corresponds to the "second input signal" of the
present invention.

When a blaze-shaped diffraction structure having a
pitch D_3 is formed on the curved surface 2a of the substrate
2, the diameter of the electron beam B (hereinafter referred
to as "beam waist BW) is adjusted to diameter D_1 by the
electron lens 16 in the prior art, as shown in Fig. 12(A).
This is scanned, for example, n-times linearly in the X
direction in the Fig. 12(A) in the resist layer L as the

layer to be patterned, whereby the side wall 3a and slope 3b

of the blaze 3 are formed, according to the prior art.

By contrast, in the electron beam depicting apparatus

1, the beam waist BW of the electron beam B is adjusted to

the diameter $D_2 = D_1$ by the electron lens 16, as shown in

Fig. 12(B). This is scanned, for example, m-times (where m

is equal to or smaller than n) in the X direction in the Fig.

12(B) in the resist layer L as the layer to be patterned,

whereby the side wall 3a and slope 3b of the blaze 3 are

formed.

In the electron beam depicting apparatus 1, the

alternating bias signal superposing circuit 115 of the sub-

deflector 112b superposes an alternating bias signal on the

deflection signal on Y direction as a sub-scanning direction

of the electron beam B or the deflection signal on Y

direction to be inputted into the input/output circuit 113d,

to put it in greater details, as shown in Fig. 13(A) and Fig.

13(B), the electron beam B is moved in the Y direction of

Fig. 13(A) and Fig. 13(B), on the resist layer L as the layer

to be patterned, as shown in Fig. 12(B). Thus, the slope 3b

of the blaze 3 is formed by snaking of electron beam B.

The amplitude of the aforementioned alternating bias

signal is adjusted according to the configuration of the

blaze 3. This adjustment is made in such a way that the amplitude on the locus of the scanning line of the electron beam B is maximized at the center of the slope 3b of the blaze 3, and is reduced as one goes closer to the side wall 3a of the blaze 3, as shown in Fig. 12(B). The details will be described later.

Incidentally, this adjustment is made because, in the patterning of the slope 3b of the blaze 3, a larger beam diameter is required in order to get a smooth form, as described above. By contrast, in the patterning of the vicinity of the side wall 3a of the blaze 3, a small beam diameter must be used in order to get a sharp rising portion. To put it another way, in the electron beam depicting apparatus 1, when the slope 3b of the blaze 3 are patterned, the electron beam B is moved in the sub-scanning direction (Y direction), as shown in Fig. 14(A) and Fig. 14(B), and scanning is performed in the main scanning direction (X direction) by snaking of electron beam B. This method allows patterning to be performed as if electron beam B having a large diameter were used for scanning.

In this example, the X direction is the same as the main scanning direction of the electron beam B. This eliminates the need of superposing an alternating bias signal

on the deflection signal on the X direction, or the deflection signal on X direction to be inputted into the input/output circuit 113b.

Further, in the electron beam depicting apparatus 1, control is made to adjust the scanning pitch (patterning interval) of the adjacent electron beams B, in response to the amplitude of the alternating bias signal superposed on the deflection signal on the Y direction as a sub-scanning direction of the electron beam 1 as described above. This will be described later in greater details.

Incidentally, in this example, when a blaze-shaped diffraction structure having a pitch D_3 is formed on the curved surface 2a of the substrate 2 by the electron beam depicting apparatus 1 in a similar fashion as before, the number of electron beam scanning operations can be reduced as compared to that in the past. As is apparent from Figs. 14 (A) and (B), this is because of the following reason: When scanning is in the X direction by snaking of the electron beam B, with the electron beam B moved in the Y direction in Figs. 14 (A) and (B), patterning in the greater range is possible, even if the width D_2 of the beam waist BW is the same as the width D_3 of the beam waist BW according to the prior art. Incidentally, in either case, the speed of

scanning in the X direction is the same. This is because

there is no difference between these two cases in the

deflection signal on the X direction as the main direction of

electron beam B, or the deflection signal on X direction to

be inputted into the input/output circuits 113a and 113b, to

put it in greater details.

Thus, in the electron beam depicting apparatus 1,

scanning is in the X direction by snaking of the electron

beam B, with the electron beam B moved in the Y direction,

and this arrangement permits patterning to be performed in

the greater range as compared to the prior art method, and

hence reduces the number of scanning operations by the

electron beam, with the result that patterning operation is

performed in a shorter period of time. Further, a smoother

shape can be gained, even if the number of scanning

operations is the same as that in the prior art.

In such a case, in order to reduce the dose of the

resist layer L as the layer to the patterned per unit area,

the electron gun controller 104 regulates and controls the

current and voltage of the electron gun power supply 102

under the control of the controller 170, thereby adjusting

(increasing) the amount of electron beam B applied from the

electron gun 12.

Going back to Fig. 11, the alternating bias signal
superposing circuit 115 includes: variable gain circuits 117a
and 117b for adjusting each of the amplitudes of the
alternating bias signals superposed on the signals to be
inputted into the input/output circuits 113b and 113d,
according to the gain external control signal from the
controller 170; and a variable frequency circuit 119 for
adjusting frequency of the alternating bias signal superposed
on the signal to be inputted into the input/output circuits
113b and 113d. Incidentally, variable gain circuits 117a and
117b can be made up of variable resistance attenuator or the
like. Further, the variable frequency circuit 119 can be
composed of a VCO (Voltage Control Oscillator) or the like.

In the electron beam depicting apparatus 1, as shown in
Fig. 12(B), this arrangement makes it possible to adjust the
amplitude A_1, A_2 (where $A_1 > A_2$) on the locus during the
scanning operation in the X direction by snaking of the
electron beam B, with the electron beam B moved in the Y
direction, in the resist layer L as a layer to be patterned.

For example, adjustment is made such a way that the
amplitude of the alternating bias signal superposed on the
deflection signal on the Y direction as the sub-scanning
direction of electron beam B, or the deflection signal on Y

direction to be inputted into the input/output circuit 113d,
to put it in greater details, in order to ensure that the
amplitude on the locus of the scanning line by the electron
beam B is maximized at the center of the slope 3b of the
blaze 3 by the variable gain circuit 117b, based on the shape
of the blaze 3, and is reduced as one goes closer to the side
wall 3a of the blaze 3. This adjustment permits adjustment
of the amplitudes A_1 and A_2 on the locus during the scanning
operation in the X direction by snaking of the electron beam
B, with the electron beam B moved in the Y direction, in the
resist layer L as a layer to be patterned, in such a way that
the $A_1 > A_2$, as shown in Fig. 12(B).

The alternating bias signal superposed on the
deflection signal on the Y direction as the sub-scanning
direction of electron beam B, or the deflection signal on Y
direction to be inputted into the input/output circuit 113d,
to put it in greater details, is a so-called radio frequency
signal. It is close to the response frequency band (cut-off
frequency), and therefore allows the variable frequency
circuit 119 to adjust the frequency on the locus during the
scanning operation in the X direction by snaking of the
electron beam B, with the electron beam B moved in the Y

direction of the figure, in the resist layer L as a layer to be patterned.

As described above, the amplitude of the alternating bias signal superposed on the signal to be inputted to the input/output circuits 113b and 113d is adjusted by the variable gain circuits 117a and 117b, based on the gain external control signal from the controller 170.

In this case, the controller 170 gets information on the shape of the blaze 3 from the shape memory table 161 of the memory 160, and performs operations according to the processing program stored in the program memory 162, thereby working out the amplitude of the alternating bias signal in response to the shape of the blaze 3 and transmitting the information on the amplitude to the variable gain circuits 117a and 117b as a gain external control signal.

The controller 170 controls the scanning pitch (patterning interval) of adjacent electron beams B, in addition to the adjustment of the amplitude on the path of the scanning line of electron beam B by the variable gain circuit 117b. To put it more specifically, in view of the influence of the proximity effect determined by the width D_2 of the beam waist BW, amplitudes A_1 and A_2 on the path of the scanning line of electron beam B, and frequency $1/T_1$ on the

path of the scanning line of electron beam B, the controller

170 determines that the patterning interval W_1 (see Fig.

12(B)) is a value that ensures the ranges influenced by

patterning do not overlap with one another, without any

portion leaking from the range influenced by patterning.

Incidentally, the influence of the proximity effect

determined by the aforementioned width of beam waist BW and

amplitude and frequency on the path of the scanning line of

electron beam B, namely, information on the range influence

by patterning is stored in the memory 160 as other

information 161d in advance.

In this case, the controller 170 performs the

operations according to the processing program stored in the

program memory 162, based on the aforementioned information

on the amplitude and frequency of the alternating bias signal

and the information on the range influence by patterning

stored in the memory 160 as other information 161d, thereby

controlling the adjustment of the scanning of the electron

beam B in patterning intervals.

(Processing of Patterning)

The following describes the aforementioned processing

of patterning of the blaze 3 in the electron beam depicting

apparatus 1 with reference to Fig. 15 and Fig. 16. Symbols

used in Figs. 15 and 16 correspond to each other.

<Acquiring step>

As shown in Fig. 15, when the blaze-shaped diffraction

structure is formed on the curved surface 2a of the substrate

2, the controller 170 allows the pattern generation circuit

120 to create the information on the pattern, based on the

information on the shape of the blaze 3 stored in the shape

memory table 161 of the memory 160 (S01). This step provides

the pattern shape data (S02). In this case, the number of

the blaze 3 to be patterned and the number of divided fields

for patterning are determined.

The controller 170 performs operations according to the

processing program stored in the program memory 162. The

patterning data on the first blaze 3 (blaze to be patterned

first), or the dose function D (x) [x = p/P] in response to

the shape of the blaze 3, to put it more specifically, is

determined, and the pitch P is set (S03).

<Scanning pitch adjustment step>

The controller 170 works out the patterning coordinate

of the line p = n (= 0), based on n = 0 (where n: initial

set value) (S05).

<Signal generation step>

The controller 170 generates the deflection signal of
the line p = n (= 0) (S06). To put it more specifically, the
deflection signal to be inputted into the sub-deflector 112b
is generated so that the line p = n (= 0) is formed by the
field control circuit 118.

<Frequency adjustment step>

The controller 170 allows the alternating bias signal
superposing circuit 115 of the sub-deflector 112b to generate
the alternating bias signal superposed on the deflection
signal of line p = n (= 0) (S07). In this case, the
amplitude of the alternating bias signal is adjusted.

<Determination step>

The controller 170 determines if p < A or not (Fig. 16)
(S08). Needless to say, since p (=0) < A is established (Yes
in S08) at first, the controller 170 permits the line p = n
(= 0) to be patterned at the scanning speed conforming to the
dose given in terms of the dose function D (x) [x = p/P]
(S09).

The controller 170 determines if n = P (S10) or not.
Needless to say, since n (= 0) = P does not hold true (No in
S10) at first, the controller 170 works out the coordinate
for patterning the line p = n (= 1) (S05), based on n = n + 1

(= 1) (S11). The steps from S05 through S11 are repeated until p > A is obtained.

S05 through S09 and S12 in Fig. 15 and symbol "p" shown in Fig. 16 denote the pitches on the p-th scanning lines to be patterned. Further, the S08 in Fig. 15 and symbol "A" in Fig. 16 show the pitch where there is no superposing of the alternating bias signal by the alternating bias signal superposing circuit 115 of the sub-deflector 112b. It is preset in the memory 160 by the setting device 181 as other information 161d.

<Superposing step>

When p > A holds true (No in S08), the controller 170 determines if p > P-B or not (S12). Needless to say, since p < P - B hold true (Fig. 6) (No in S12) at first, the controller 170 starts the superposing operation of the alternating bias signal through the alternating bias signal superposing circuit 115 of the sub-deflector 112b (S13).

<Scanning step>

The controller 170 permits the line p = n to be patterned at the scanning speed conforming to the dose given in terms of dose function D (x) [x = p/P] (S09). In this case, however, the aforementioned alternating bias signal superposing circuit 115 of the sub-deflector 112b superposes

alternating bias signals to the deflection signal on the Y direction as the sub-scanning direction of electron beam B, or the deflection signal on Y direction to be inputted into the input/output circuit 113d, to put it in greater details. Thus, scanning operation is carried out by the electron beam B shifted in the sub-scanning direction and applied in a snake-like motion.

The controller 170 determines if p = n or not (S10). Needless to say, since p = n does not hold true (No in S10), the controller 170 works out the coordinate for patterning the line p = n (S05), based on n = n + 1 (S11). The steps from S05 through S11, namely, <Scanning pitch adjustment step> through <Scanning step> are repeated until p > P - B is obtained.

The symbol "B" given in the S12 of Fig. 15 and Fig. 16 denotes the pitch showing the range where alternating bias signal is not superposed by the alternating bias signal superposing circuit 115 of the sub-deflector 112b. It is set in the memory 160 as other information 161d by the setting device 181.

When the p > P - B has been achieved (Yes in S12), the controller 170 terminates the superposing operation of alternating bias signal by the alternating bias signal

superposing circuit 115 of the sub-deflector 112b (S14).

Then the controller 170 permits the line p = n to be

patterned at the scanning speed conforming to the dose given

in terms of the dose function D (x) [x = p/P] (S09). Then it

determines if n = P or not (S10). Needless to say, since n =

p does not hold true (No in S10), the controller 170 works

out the coordinate for patterning the line p = n (S05), based

on n = n + 1 (S11). The steps from S05 through S11, namely,

<Scanning pitch adjustment step> through <Scanning step> are

repeated until n = P is obtained.

When n = P holds true (Yes in S10), the controller 170

determines if pattering of all blazes 3 has terminated or not

(S15). Needless to say, since patterning is not terminated

at first (No in S15), the patterning data for the next blaze

3 is created (S16). The steps from S04 through S16, namely,

<Scanning pitch adjustment step> through <Scanning step> are

repeated until pattering of all blazes 3 terminates (Yes in

S15).

[MANUFACTURING METHOD OF THE METALLIC MOLD]

The aforementioned precision working of a diffraction

structure or the like on a substrate by the electron beam

depicting apparatus of the present invention has been

disclosed in the above description. The following describes

the process related to all the aforementioned steps, i.e. the process of manufacturing the metallic mold for producing an optical lens such as optical element through molding.

In the first place, a metallic mold (electroless nickel, etc.) is working by machining (machining process). As shown in Fig. 17(A), the metallic mold is used to produce a substrate 200A having a basic optical surface consisting of predetermined curved surfaces, through plastic molding (plastic molding process). Further, substrate 200A is dried after having been washed.

Then the substrate 200A is subjected to surface treatment (plastic surface treatment process). Silver deposition, for example, is carried out in this process. To put it more specifically, the substrate 200A is positioned and the spinner is rotated while a resist L is dropped, whereby spin coating is performed. Further, pre-baking is also carried out. This arrangement provides a substrate 200A with the resist film formed on the basic optical surface.

After pin-coating, the thickness of the aforementioned resist film is measured and the resist film is evaluated (resist film evaluation process). Further, as shown in Fig. 17(C), while the substrate 200B is positioned and the substrate 200B is controlled through X, Y and Z axes,

patterning (exposure) is performed on the resist film by

electron beam B, in conformity to the predetermined pattern

(diffraction structure in this case) to be formed on the

substrate 200B.

The resist film L on the substrate 200B is subjected to

surface smoothing treatment (surface smoothing process).

Further, as shown in Fig. 17(D), processing of development is

applied while the substrate 200B is positioned (development

process). In this case, the range affected by patterning

with electron beam B, i.e. the exposed portion is removed,

and a predetermined pattern 202 is formed on the basic

optical surface. Then surface hardening treatment is

performed.

The next is the process of evaluating the resist shape

by SEM observation and use of a film thickness measuring

instrument (resist shape evaluation process).

Dry etching is carried out if etching is required to

get a predetermined shape, namely if a predetermined shape is

to be gained by further etching of the resist shape obtained

in the process of development. In this way, a mother die as

a die master having a predetermined shape is obtained. Metal

is evaporated on the resist surface of the mother die 200C

and pre-treatment for electroforming of the metallic mold is carried out (metal evaporation process).

As shown in Fig. 17(E), electroforming is applied to the mother die 200C having been subjected to surface treatment, thereby creating an electroformed member 203 with a predetermined structure transferred to the mother die 200C. Then processing is applied to separate between the mother die 200C and metallic mold 204, as shown in Fig. 17(F), and the metallic mold 204 is obtained by working the external shape.

Surface treatment is applied to the metallic mold 204 separated from the mother die 200C having been subjected to surface treatment (metallic mold surface treatment process). Then the metallic mold 204 is evaluated.

Thus, the aforementioned steps provide easy production of the metallic mold for injection molding of the optical element to be described later.

[MANUFACTURING METHOD OF THE OPTICAL ELEMENT]

The above description has explained the process of manufacturing the metallic mold for producing an optical lens such as optical element through molding. The following describes the process related to all of the aforementioned step, i.e. the process of manufacturing an optical lens such as optical element through molding.

The metallic mold 204 having been evaluated as described above is used to perform plastic molding for getting a molded product 300, as shown in Fig. 18(A) (plastic molding process). Then as shown in Fig. 18(B), the molded product 300 is dried after having been washed. The molded product 300 is then evaluated. If it has passed the evaluation test, the molded product 300 is regarded as a commercial optical element.

The following describes a concrete embodiment of the present invention.

Material to be patterned: Positive resist coated on
         the PMMA resin

Targeted finish surface: Surface roughness < Ra 10 nm

Dose (irradiation amount of electron beam):

    Acceleration voltage; 50 kV

    Probe current; approximately 1 nA

    Dose; up to 300 $\mu C/cm^2$

Scanning speed in the main scanning direction:

    100 nm/μ sec through 15 nm/μ

Deflection frequency in the sub-scanning direction:

    2 MHz at present

Deflection amplitude in the sub-scanning direction:

Amplitude overlapping with at least

adjacent scanning line

Fig. 19(A) and Fig. 19(B) show the result of patterning

under the aforementioned conditions. Fig 19(A) shows the

profile of the surface of the patterned resist surface

without superposing alternating bias (as a comparative

example). Fig 19(B) shows the profile of the surface of the

patterned resist surface with superposing alternating bias

(as a particular embodiment). With superposing alternating

bias, the roughness of the patterned resist surface is no

more than 5 nm (Ra). Without superposing alternating bias,

the roughness of the patterned resist surface is

approximately 10 nm (Ra). As mentioned in the above, more

smooth surface can be obtained with superposing alternating

bias.

The deflection frequency in the sub-scanning direction

is preferred to be capable of deflecting one cycle or more in

the sub-scanning direction within one-clock cycle. To put it

another way, it is preferred that the deflection frequency in

the sub-scanning direction be equal to or greater than the

dot clock frequency of the main scanning (normally, about 10

MHz). In practice, it is difficult to adopt such a frequency

due to the problems involved in the circuit response.

Further, a smooth finish surface cannot be easily obtained on the low-dose portion (high-speed scan portion in the main scanning direction). There is no difference in the deflection frequency of several MHz.

The above arrangement ensures easy manufacture of an optical element.

As described above, the electron beam depicting apparatus of the present invention provides a smooth sloped surface and a sharp rising portion of the edge using a small-diagram beam, and reduces the patterning time at the same time.

Disclosed embodiment can be varied by a skilled person without departing from the spirit and scope of the invention.